"FACING THE REALITY OF OPERATING WITH MINIMUM TDRSS SUPPORT"

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ABSTRACT

In September 1996, NASA made the decision to build ground stations in Alaska and Norway. These stations will provide the primary communications link for science data downlink from the polar-orbiting Earth Observing System (EOS) series of spacecraft. This decision was based on a two-year study evaluating the advantages and disadvantages of using ground stations versus using the Space Network (SN)/Tracking and Data Relay Satellite System (TDRSS) for downlinking high rate science data from earth-orbiting spacecraft. The Earth Science Data and Information System (ESDIS) Project at GSFC was tasked with building the EOS Polar Ground Stations (EPGS) as part of the EOS Ground System (EGS).

Since the first EOS spacecraft, AM-1, had already been designed with an onboard communications system that uses TDRSS as its primary mode of transmitting science data to the ground, an "adaptive" (or adaptable) ground system architecture was conceived such that it can support either or both the TDRSS and ground station requirements. The "adaptive" concept led to changing the design of the EOS ground system interface at the SN/TDRSS White Sands Complex in New Mexico to the same architecture that will be implemented at the ground stations. In addition, due to the challenges associated with the ground stations being located in distant remote areas, a conscious approach was taken to minimize the operations functions and staffing at the ground stations and consequently, at White Sands. This paper addresses the changes to the TDRSS-based system architecture and operations concept to implement the adaptive (EPGS-based) concept.

1.0 INTRODUCTION

EOS comprises a major portion of NASA's Earth System Science Enterprise Program (formerly known as "Mission to Planet Earth"). EOS is the first comprehensive system designed specifically to study the Earth as a complex series of interactions between life, air, water and land. It consists of numerous instruments on multiple spacecraft and a distributed EOS ground system. Over a 15-18 year period, EOS spacecraft and complementary international missions will provide integrated measurements of the Earth's processes, resulting in an environmental data base on global climate change.

The EOS Data and Information System (EOSDIS) is the major ground system developed to support EOS. The EOSDIS will provide EOS spacecraft command and control, data processing, product generation, and data archival and distribution services for U.S. EOS spacecraft. Data from EOS instruments on other Earth science missions [e.g., Tropical Rainfall Measuring Mission (TRMM)] will also be processed, distributed, and archived in EOSDIS.

2.0 CHANGES TO THE EOS CONCEPT

Since its establishment as a major NASA program in 1990, EOS has undergone numerous reviews. These reviews recommended changes to make the program components more resilient, flexible, and cost-effective. In accordance with NASA's goal of "faster, better, cheaper", the spacecraft component was downsized from the original "large observatories with numerous instruments " to "smaller spacecraft with few instruments". Similarly, the ground system was directed to streamline to provide a cost-effective end-to-end system.

In 1994, a study was commissioned to look at the advantages and disadvantages of using an X-band communications system as the primary mode for downlinking high rate (up to 150 Mbps) EOS science data instead of the TDRSS, which was part of the baseline concept and was implemented for the first spacecraft, EOS AM-1. The two-year study culminated in a decision by NASA headquarters that future (downsized) EOS spacecraft would utilize X-band for transmitting data to the ground, thus resulting in reduced cost for the flight segment (less weight, power, and overall cost for the X-band system versus the TDRSS-compatible (high gain antenna/TDRSS transponder) system).

Even prior to the official decision in the fall of 1996, ground system personnel had started to reshape the ground system design for the EOSDIS components responsible for flight control, data downlink, and initial data processing to determine the most efficient and effective ways to provide these functions. An intensive examination of all mission requirements was performed and as appropriate, some requirements were deleted/descoped without significant degradation of services. The primary result of this effort was the formation of an "adaptive downlink" architecture approach (see section 3.2).

As a result of the Headquarters decision in the fall of 1996, ground system personnel were directed to implement the EPGS-based support concept, that is, to develop the polar ground stations as the prime data acquisition interface with EOS spacecraft beginning with the PM-1 spacecraft.

3.0 GROUND SYSTEM ARCHITECTURE CHANGES

Existing NASA ground station resources in 1996 did not have the capability to handle data at 150 Mbps. After investigating sites in Norway, Greenland, Alaska, and McMurdo, the decision was made to implement the EPGS at the Poker Flat Research Range, Fairbanks, Alaska, and one located at Longyearbyen, Spitsbergen, Svalbard, Norway. Both sites provide optimum coverage for the EOS spacecraft (see Table 1, EOS-AM1 and PM-1 coverage at 5 degree elevation**)**. These sites would be developed to provide the data acquisition capability for the high rate (up to 150 Mbps) X-band science data downlink as well as the capability to handle the S-band forward and return links (2 kbps uplink, 16 kbps realtime housekeeping and up to 512 kbps housekeeping playback). These stations would provide prime support for all the EOS spacecraft starting with the second spacecraft, PM-1 (launch scheduled for December 2000). For the first spacecraft, EOS AM-1, TDRSS will be the prime mode for getting science data to the ground. After the PM-1 on-orbit operations are nominal, AM-1 operations are planned to transition from TDRSS support to the EPGS.

3.1 POLAR GROUND STATION IMPLEMENTATION

Goddard is currently implementing a Svalbard Ground Station (SGS) system in Norway and an Alaska Ground Station (AGS) system with generic X-band and S-band capabilities for multi-mission support to NASA low earth orbiting (LEO) spacecraft.

The implementation at the 2 EPGS sites will be done in two phases:
Phase I: Implementation of the EPGS will begin with the integration of mission specific equipment into the SGS and AGS systems to provide back-up support for the AM-1 spacecraft.

in the event of TDRSS communications failure. Phase I will include the capability to support Landsat-7 communications. Recently, the Earth Orbiter-1 (EO-1) mission (launch in May 1999) and QuikScat mission (launch in November 1998) have also requested EPGS support; specific capabilities to support these missions will be included as part of Phase I.

Table 1. EOS AM-1 And PM-1 Coverage

Orbit	# Minutes (at 5 degree elevation)		
	Alaska	Norway	Total
1	0	11.9	11.9
2	0	12.2	12.2
3	8.8	12.9	21.7
4	12.8	13.5	26.3
5	13.4	13.3	26.7
6	11.7	12.0	23.7
7	8.5	10.1	18.6
8	6.4	8.7	15.1
9	8.3	9.2	17.5
10	11.5	11.2	22.6
11	13.4	12.8	26.2
12	12.9	13.5	26.5
13	9.3	13.3	22.5
14	0	12.5	12.5
Total	116.9	167.1	**284.0**
Average	8.3	11.9	**20.3**

Phase II: Concurrent with the Phase I ground station implementation, analysis and design activities are being performed to support Phase II objectives. These activities include mission modeling, loading analyses, architecture development and review, and user RF ICD development support. The architecture study includes an evaluation of the use of existing NASA institutional assets, if deemed appropriate, to meet the Phase II project objectives and requirements. The capabilities of the initial ground stations will be enhanced and/or upgraded to provide the additional capabilities that are needed to support all the EOS missions in the post-2000 timeframe.

As shown in Figure 1, these ground station systems consist of several major architectural components: the Radio Frequency (RF) subsystem, baseband data processing subsystem, monitor and control subsystem (MCS), and commercial telecommunication subsystem. Collocated at the EPGS will be the EDOS Ground Station Interface Facility (GSIF) which will provide the interface for the X-band high rate science data stream between the RF subsystem and the EDOS Level Zero Processing Facility (LZPF) at GSFC. EDOS is discussed later in Section 3.3.

RF Subsystem: The RF subsystem provides space-to-ground-link telecommunication channels for receipt of high rate science telemetry data, receipt of spacecraft housekeeping telemetry data, and transmission of spacecraft commands. Below are the characteristics of the communication channels for Landsat-7 and AM-1 support.

- X-band telemetry data: up to 150 Mbps (up to 3 independent channels)
- S-band telemetry data: 1 kbps to 512 kbps
- S-band command data: 125 bps to 2 kbps

Baseband Processing Subsystem: The baseband processing subsystem performs data quality checks, records the data on tape, and establishes compatibility between the raw digital data at the RF subsystem interface and the data systems at GSFC receiving/sending the data.

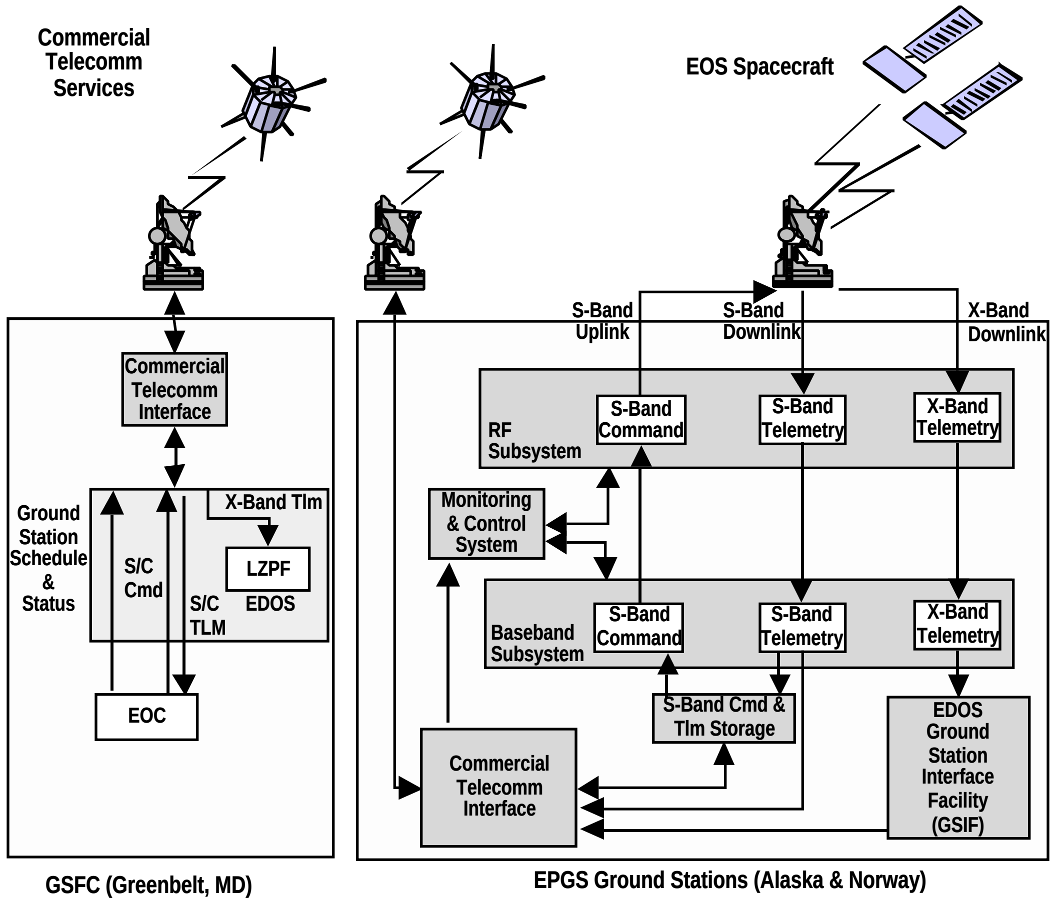

Figure 1. EPGS System Overview

The X-Band Return functions include: frame synchronization on the received Consultative Committee for Space Data Systems (CCSDS) Channel Access Data Units (CADUs) at 150 Mbps (for data quality monitoring purposes only); Reed-Solomon (R-S) error detection and correction (EDAC) of the data (for data quality monitoring purposes only); recording of the Landsat-7 data on tape for later shipment; EOS AM-1 contingency backup operations capability for tape recording and shipment to the EDOS Level 0 Data Processing Facility.

The S-Band Return functions include: data quality checks on received telemetry data; tape backup of all S-band return spacecraft housekeeping data; and, conversion to a standard transport protocol for transmission to GSFC across the commercial telecommunications interface.

The S-Band Forward functions include: protocol conversion of data received from GSFC and forward a clock and data signal to the RF interface; temporary storage of data to ensure data stream continuity as necessary; and, verification of the integrity of received data.

Monitor and Control Subsystem: The MCS will gather parameters from RF and baseband processing equipment, and perform autonomous monitoring of key equipment health parameters during a pass. It will also configure the station for pass support and conduct system performance tests.

Commercial Telecommunications Interface: This subsystem consists of multiplexer equipment provided by the NASA Integrated Services Network (NISN)/EOS Backbone Network (Ebnet). This subsystem will enable the transport of data from the EPGS sites to the destination user facilities via commercial telecommunications satellite or via fiberoptic links.

3.2 SCHEDULE

Phase I, which consists of the AM-1 back-up facilities, will be operational by July, 1998 in readiness for the AM-1 launch in December, 1998. The period of back-up operations status will extend from launch until June, 2000 when the Phase II system will be ready for prime support of PM-1.

For the full system implementation (Phase II), additional antennas and associated ground station equipment will be installed during the summer of 1999 based on the results of the architecture development activities and reviews. These equipment will provide additional X-band telemetry downlink strings, S-band telemetry downlink strings, and S-band command uplink strings.

The first phase of remote monitor and control capability will also be installed during the summer of 1999. Equipment status and critical control parameters will be transmitted via existing telecommunications links. This will give the EOC operations personnel a chance to familiarize themselves with the system and refine automated control and failover concepts for later implementation.

The Phase I telecommunications subsystem will consist of low rate (T-1 line) communication links to transport the S-band downlinked data to GSFC. (The X-band data will be recorded on tape, as needed, and shipped to the GSFC). However, if the ground stations are forced into a primary support role due to a TDRSS communications failure, rapid activation of high rate telecommunications links (for the X-band science data stream) will take place so that tape-based operations may be held to a minimum duration. All telecommunications equipment will be put in place and tested during phase I to support data return via commercial telecommunications links, but an actual high rate (T-3 line) telecommunications service contract will not be established until the PM-1 time frame or when required due to a failure, whichever is sooner.

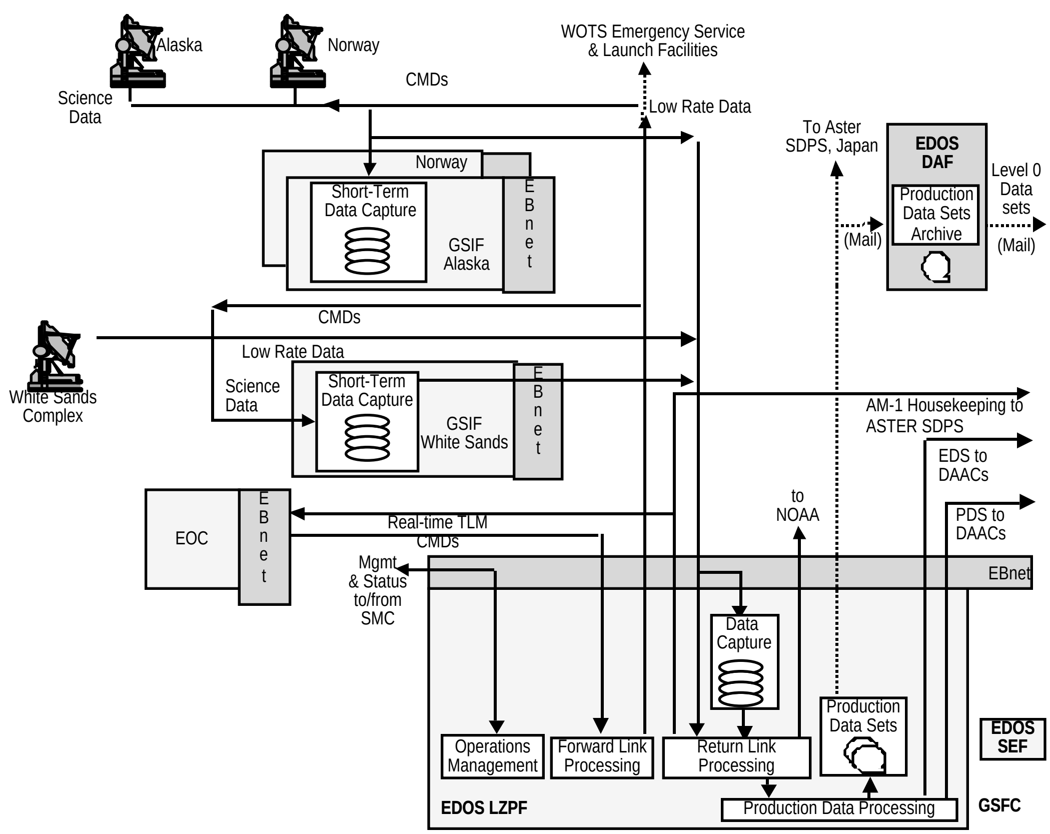

Figure 2. EDOS Configuration

3.3 REALLOCATION OF EDOS FUNCTIONS

As shown in Figure 2, EDOS Configuration, the new ground system design features an "adaptive" front-end interface. The ground station interfaces with the control center (EOS Operations Center) and the data handling system known as the EOS Data and Operations System (EDOS) are basically the same, that is, the interface accommodates both the TDRSS ground terminal interface at White Sands, New Mexico and the polar ground station interfaces at Alaska and Norway.

In implementing this adaptive front-end, a conscious effort was made to minimize the cost and problems associated with operating at the remote EPGS sites. Thus, EDOS functions which had been previously consolidated at White Sands (also to reduce the cost of the original TDRSS-based design) had to be re-examined in terms of these functions being located at the EPGS sites. The adaptive design, coupled with the objective of simplifying and minimizing ground station operations, resulted in the migration of some EDOS functions back to GSFC. This includes the level zero processing, packet quality monitoring, and the low rate interface. See Table 2, Ground System Function Allocation—Original (at White Sands) vs. Adaptive Front-End Approach (at White Sands/EPGS/GSFC).

Table 2. EOS Ground System Function Allocation

Ground System Function	Original	Adaptive		
	(at White Sands)	at White Sands	at EPGS	at GSFC
Spacecraft uplink/downlink interface	X	X	X	
EDOS High Rate Interface	X	X	X	X
EDOS Low Rate Interface	X			X
EDOS raw science data capture	X	X	X	X
EDOS raw HK data capture	X			X
Realtime processing (HK)	X			X
Playback Processing (HK)	X			X
Level Zero Processing	X			X
Expedited Data Processing	X			X
Packet Quality Monitoring	X			X
Command interface w/ the EOC	X			X
System Monitoring Interface	X			X

4.0 OPERATIONS USING MINIMUM TDRSS SUPPORT

By the time the third EOS spacecraft, ICESat-1, is launched in July 2001, both EOS-AM1 and PM-1 will be getting their prime support from the EPGS. In addition, other earth science spacecraft will require support from the EPGS. Although Landsat-7 contacts will be scheduled primarily through the ground station at the Earth Resources Observation System (EROS) Data Center in South Dakota, the EPGS has a requirement to support 6 passes per day (2 ascending node (AN) and 2 descending node passes over Alaska and 2 passes over Norway). Other pre-2000 spacecraft, i.e., EO-1, QuikScat and TOMS-EP, have also requested support from the EPGS. See Table 3, Spacecraft Supported by the EPGS.

The current operations concept does not completely do away with the TDRSS interface. Minimum use of the SN/TDRSS is planned, mostly during launch and early orbit. TDRSS support will also be scheduled during spacecraft maneuvers, and emergency or contingency situations. In addition, tracking and time correlation functions are planned to be performed via TDRSS for AM-1 and PM-1. Although it does not carry a TDRSS transponder, EOS ICESat-1 (previously known as EOS LAM-1) is looking into using TDRSS for obtaining housekeeping data during a 40-minute period following launch before it is in view of a polar ground station.

Table 3. Spacecraft Supported By the EPGS

Mission Profiles

Mission	Orbital Data Volume	Onboard Storage Capacity	Downlink Rates (bps)	Time Needed for X-Band Dump	Command Requirements (Freq., Duration)	Mission Period[1]	Expected EPGS Usage/Day
AM-1	110 Gbits	160 Gbits	150M (X-PB) 512K (S-PB) 16K (S-RT)	12.22 min/orbit	1 pass per day for loads RT each pass for SSR dump control	NET 12/98 - 12/04	All passes Required
Landsat-7	Imaging: 878 Gbits/day 45MB/day H/K	378 GB	150M (X-PB/RT) 256K (S-PB) 1 or 4K (S-RT)	Use all scheduled passes (6/day planned)	AGS DN passes for loads uplinks (2/day) RT each pass for PB	7/98 - 5/05	AGS: 2AN, 2DN SGS: 2 passes (6 passes total)
EO-1	80 Gbits/Day	40 Gbits	105M (X-PB) 1M (S-PB/RT) (lower LEO & B/U rates)	12.7 min/day	*1 pass per day for loads* *RT each pass for SSR dump control*	5/99 - 5/00	2 SGS Passes
PM-1	47 Gbits	136 Gbits	150M (X-PB) 524K (S-PB) 16K (S-RT)	5.22 min/orbit	1 pass per day for loads RT each pass for SSR dump	12/00 - 12/06	All passes (1 pass/ orbit min)
ICESAT Compressed (Uncom-pressed)	1.6 Gbits (2.97 Gbits)	24 Gbits	40M (X-PB) 16K (S-RT) 256K (S-PB)	10.8 min/day (19.8 min/day)	4-6 RT pass/day for SSR/DSU dump control 1 or 2 loads per day	7/01 - 7/06	4 passes/day
CHEM-1	33 Gbits	88 Gbits	150M (X-PB) 524K (S-PB) 16K (S-RT)	3.67 min/orbit	1 pass per day for loads RT each pass for SSR dump control	12/02 - 12/08	All passes (1 pass/ orbit min)

Note 1: Mission durations assume 6 year lifetimes for AM, Landsat, PM, and CHEM spacecraft, and 5 year lifetimes for ICESAT spacecraft.
Note 2: Numbers in parenthesis are the minimum number and duration of tracking passes (per day) needed to support mission accuracy requirements if all tracking data was provided by EPGS.
Worst case EPGS loading year is 2004; AM-1, Landsat, PM-1, CHEM-1, ICESAT, and AM-2 all supported simultaneously (6 spacecraft).

There are basic operational considerations that must be taken into account when operating with ground stations instead of with TDRSS. Just like the TDRSS-based concept, scheduling of ground station resources for the support of several missions need to be coordinated and in cases of conflict, arbitrated. Unlike TDRSS conflicts, which involve conflicting user requests, ground station conflicts can be easily predicted through simple orbit propagation. The Wallops Orbital Tracking Information System, a scheduling system developed by the Wallops Flight Facility for the support of the Wallops ground resources, will be used for scheduling the EPGS resources. Spacecraft priority guidelines will be have to be clearly spelled out. As a rule, EOS missions will have top priority in case of conflict with other non-EOS spacecraft. Prioritization among the different EOS spacecraft will be done at the EOS Operations Center, based on priorities set by the program office and/or EOS scientists.

It should be noted that ground station contact scheduling is often easier than TDRSS scheduling simply because it is essentially deterministic; there are limited opportunities for communications between a ground station and a LEO satellite. Low earth orbiters ground station scheduling can be as simple as “schedule a comm event at all ground station passes”. TDRSS scheduling is complicated by the fact that coverage is virtually unlimited, and contact times are often arbitrarily selected by each mission without coordination of potential conflicts (the Network Control Center coordinates the resolution of schedule conflicts with the users).

This ease of scheduling comes with a price, however; ground stations provide limited coverage. This can have a major impact on anomaly resolution options. The spacecraft operated through ground stations must be more robust than one operated through TDRSS. It must survive on its own during periods of communications blackouts, even under anomalous conditions. It should be noted that communications systems can be designed that support low-rate communications to both ground stations and TDRSS. The use of such a system allows the use of ground stations for primary communications, with TDRSS available as a low-rate backup for emergency support, as required. TDRSS Project personnel at GSFC are developing ways of using TDRSS to support low-rate communications from LEO spacecraft without a TDRSS transponder. This has been demonstrated on-orbit already, and greatly expands the number of satellites that TDRSS can support for nominal or emergency communications.

In addition to coordination of scheduling, there must also be coordination in case of radio frequency interference between /among the different spacecraft. With the availability of two antennas (both S and X-bands) at each EPGS site in its final operational configuration, interference may occur between certain spacecraft when there is overlapping support. Again, operations personnel must base their prioritization guidelines set by the program office.

In order to minimize support conflicts, operations consideration must be taken into account in all stages of mission development. This includes constellation design of a multi-satellite system like EOS. EOS AM-1, PM-1, and CHEM-1 mission all operate in the same sun-synchronous orbit plane at the same altitude. Landsat-7 and EO-1 are also targeted for this same orbit plane (and plan to fly in formation within one minute of each other) to obtain synergistic observations along the same orbit track. Operations personnel for EOS spear-headed constellation design to space the spacecraft around the orbit plane based on expected downlink data volume. This early effort will minimize ground station contact conflicts and spread out the demand for communications bandwidth between the ground stations and EDOS, the gateway to the control center and science data archives.

Operating the ground stations themselves introduces a complexity to the EOS missions simply due to their remote locations. For this reason, EPGS design has focused on minimizing processing complexity at the ground stations, simplifying interfaces, and automating station configuration and operations as much as possible. This approach minimizes, but does not eliminate operations and maintenance staffing requirements at the remote ground stations. EOS will take advantage of existing infrastructure and personnel at the polar sites.

5.0 CONCLUSION

Design of the ground system elements that interface with the ground stations has been simplified to accommodate the interfaces at both the TDRSS ground terminal and the polar sites. In addition, automation is being incorporated for the ground terminal interfaces (as appropriate) to minimize operations staffing. Operations planning is maintaining a close look at the constellation design to ensure efficient planning and scheduling of the EPGS contacts for the various spacecraft, and also the timely transmission of the high rate science data back to the GSFC. The ESDIS Project will continue to evaluate mission requirements to ensure that the proper capabilities are being implemented for the final post-2000 EPGS configuration.

6.0 ACKNOWLEDGMENTS

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7.0 REFERENCES

1. MTPE/EOS Reference Handbook, 1995
2. EOS Polar Ground Stations Level II Requirements Document, 1997
3. PM-1 Mission Operations Concept, 1997
4. I AM-1 Mission Operations Concept, 1997